



**AFRL-RX-WP-TM-2013-0229**

**INNOVATIVE APPROACH FOR HIGH STRENGTH,  
HIGH THERMAL CONDUCTIVE COMPOSITE  
MATERIALS: Data Base**

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**NOVEMBER 2013  
Final Report**

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## 1.0 SUMMARY

Hybrid matrix (polymer and thermal conductivity filler) pitch fiber composites were developed. Testing was performed on multiple pitch fiber types, from which we were able to down select K6356U pitch fiber with balanced TC and strength properties. A prepreg processing line was created capable of infusing the unidirectional pitch fiber tape. This processing line has the capability to be used with other fiber types as well. Aluminum hybrid matrix composites were manufactured using a resin exfusion process as well as conventional compression molding, so as to compare the two processes. It was found that compression molding outperforms autoclaving in regards to both thermal and mechanical properties.

### Highlights:

- Increasing the thermal and mechanical properties of aluminum particulate pitch fiber composites over control composites
- Creating a robust prepreg processing line to infuse unidirectional pitch fiber tape that can be used with other fibers...Pan-based carbon or glass
- In-plane TC numbers reaching 25-30 W/m\*K for quasi-isotropic pitch fiber composites
- Transverse TC numbers more than double that of control pitch fiber composites
- Compression molding process outperforms autoclaving in mechanical and thermal properties using the same prepreg material and process conditions (better particle packing behavior)
- Cost per pound of P<sup>2</sup>SI's prepreg material drops by 38%/pound making it a viable alternative to steel or aluminum components. The price to produce P<sub>2</sub>SI's hybrid-aluminum-filled pitch fiber prepreg is: \$88/pound.

## 2.0 DATABASE

Table 1: Autoclaved 0° Flexure Strength and Modulus

|  |   |                 |                   |                            |                   |                         |                   |                 |               |
|--|---|-----------------|-------------------|----------------------------|-------------------|-------------------------|-------------------|-----------------|---------------|
| <b>Material:</b>                                   | K6356U/ 30% Alum. Filled /862W Prepreg Autoclaved |                 |                   |                            |                   |                         |                   |                 |               |
| <b>Matrix Content:</b>                             | 62.91   | % (w/w)         |                   | <b>Composite Density:</b>  | 1.704             | <b>g/cm<sup>3</sup></b> |                   |                 |               |
| <b>Fiber Volume:</b>                               | 37.10   | %               |                   | <b>Fiber Areal Weight:</b> | 154.0             | <b>gsm</b>              |                   |                 |               |
| <b>Ply Thickness:</b>                              | 0.0078  | <b>inches</b>   |                   |                            |                   |                         |                   |                 |               |
| <b>Test Method:</b>                                | ASTM D790: 0°-Flexure Strength and Modulus        |                 |                   |                            |                   |                         |                   |                 |               |
| <b>Normalization:</b>                              | Normalized to 50% Fiber volume                    |                 |                   |                            |                   |                         |                   |                 |               |
| <b>Test Temperature (°F)</b>                       | RT  |                 | RT                |                            | 250               |                         | 250               |                 |               |
| <b>Moisture Saturation (%)</b>                     | 0.0   |                 | 0.212             |                            | 0.0               |                         | 0.212             |                 |               |
| <b>Environmental Conditioning</b>                  | Dry   |                 | Wet               |                            | Dry               |                         | Wet               |                 |               |
| <b>Mechanical Property</b>                         | <b>Normalized</b>                                 | <b>Measured</b> | <b>Normalized</b> | <b>Measured</b>            | <b>Normalized</b> | <b>Measured</b>         | <b>Normalized</b> | <b>Measured</b> |               |
| <b>Flexure Strength (<math>\sigma_{11}</math>)</b> | <b>Mean MPa (ksi)</b>                             | 662<br>(96.0)   | 491<br>(71.2)     | 603<br>(87.4)              | 447<br>(64.8)     | 445<br>(64.5)           | 330<br>(47.9)     | 337<br>(48.9)   | 250<br>(36.3) |
|  | <b>Minimum</b>                                    | 637<br>(92.4)   | 473<br>(68.6)     | 560<br>(81.2)              | 416<br>(60.3)     | 423<br>(61.3)           | 314<br>(45.5)     | 325<br>(47.0)   | 241<br>(34.9) |
|  | <b>Maximum</b>                                    | 673<br>(97.6)   | 499<br>(72.4)     | 657<br>(95.3)              | 487<br>(70.6)     | 475<br>(68.9)           | 353<br>(51.2)     | 351<br>(50.9)   | 260<br>(37.7) |
|  | <b>Standard Deviation MPa (ksi)</b>               | 15<br>(2.18)    | 11<br>(1.60)      | 40<br>(5.8)                | 30<br>(4.4)       | 23<br>(3.3)             | 17<br>(2.5)       | 10<br>(1.5)     | 7<br>(1.0)    |
|  | <b>Number Specimens</b>                           | 5               | 5                 | 5                          | 5                 | 4                       | 4                 | 5               | 5             |
| <b>Flexure Modulus (<math>E_{11}</math>)</b>       | <b>Mean GPa (msi)</b>                             | 90.6<br>(13.1)  | 67.2<br>(9.7)     | 92.1<br>(13.4)             | 68.4<br>(9.9)     | 95.0<br>(13.8)          | 70.5<br>(10.2)    | 63.2<br>(9.2)   | 46.9<br>(6.8) |
|  | <b>Minimum</b>                                    | 88.0<br>(12.8)  | 65.3<br>(9.5)     | 88.3<br>(12.8)             | 65.5<br>(9.5)     | 92.0<br>(13.3)          | 68.0<br>(9.9)     | 55.1<br>(8.0)   | 60.4<br>(8.8) |
|  | <b>Maximum</b>                                    | 94.2<br>(13.7)  | 69.9<br>(10.1)    | 95.2<br>(13.8)             | 70.7<br>(10.3)    | 98.0<br>(14.2)          | 73.0<br>(10.6)    | 81.4<br>(11.8)  | 40.9<br>(5.9) |
|  | <b>Standard Deviation GPa (msi)</b>               | 2.5<br>(0.4)    | 1.8<br>(0.3)      | 2.6<br>(0.4)               | 1.9<br>(0.3)      | 3.3<br>(0.5)            | 2.4<br>(0.3)      | 11.1<br>(1.6)   | 8.2<br>(1.2)  |
|  | <b>Number Specimens</b>                           | 5               | 5                 | 5                          | 5                 | 4                       | 4                 | 5               | 5             |
| <b>Peak Strain (<math>\epsilon_{11}</math>)</b>    | <b>Mean (%)</b>                                   | NA              | 1.057             | NA                         | 0.903             | NA                      | 0.775             | NA              | 1.302         |
|  | <b>Minimum</b>                                    |                 | 0.972             |                            | 1.150             |                         | 0.700             |                 | 0.995         |
|  | <b>Maximum</b>                                    |                 | 1.112             |                            | 0.725             |                         | 0.880             |                 | 2.047         |
|  | <b>Standard Deviation (%)</b>                     |                 | 0.061             |                            | 0.157             |                         | 0.076             |                 | 0.435         |
|  | <b>Number Specimens</b>                           |                 | 5                 |                            | 5                 |                         | 5                 |                 | 5             |

Table 2: Compression Molded 0° Flexure Strength and Modulus

|  |   |                 |                   |                            |                               |                 |              |
|--|---|-----------------|-------------------|----------------------------|-------------------------------|-----------------|--------------|
| <b>Material:</b>                             | K6356U / 30% Alum. Filled / 862W Compression Molded |                 |                   |                            |                               |                 |              |
| <b>Matrix Content:</b>                       | 62.91 (1-3)   | % (w/w)         |                   | <b>Composite Density:</b>  | 1.782 (1) 1.834 (2) 1.839 (3) | g/cc            |              |
| <b>Fiber Volume:</b>                         | 38.50 (1) 34.40 (2) 36.60 (3)                       | %               |                   | <b>Fiber Areal Weight:</b> | 154.00 (1-3)                  | gsm             |              |
| <b>Ply Thickness:</b>                        | 0.0072 (1) 0.0084 (2) 0.0079 (3)                    | inches          |                   |                            |                               |                 |              |
| <b>Test Method:</b>                          | ASTM D790: 0°-Flexure Strength and Modulus          |                 |                   |                            |                               |                 |              |
| <b>Normalization:</b>                        | Normalized to 50% Fiber volume                      |                 |                   |                            |                               |                 |              |
| <b>Test Temperature (°F)</b>                 | CMP-1 RT  |                 | CMP-3 RT          |                            | CMP-2 250                     |                 |              |
| <b>Moisture Saturation (%)</b>               | 0.0   |                 | 0.212             |                            | 0.0                           |                 |              |
| <b>Environmental Conditioning</b>            | Dry   |                 | Wet               |                            | Dry                           |                 |              |
| <b>Mechanical Property</b>                   | <b>Normalized</b>                                   | <b>Measured</b> | <b>Normalized</b> | <b>Measured</b>            | <b>Normalized</b>             | <b>Measured</b> |              |
| <b>Flexure Strength</b><br>( $\sigma_{11}$ ) | <b>Mean MPa (ksi)</b>                               | 735 (107)       | 566 (82)          | 641 (93)                   | 469 (68)                      | 567 (82)        | 390 (57)     |
|  | <b>Minimum</b>                                      | 688 (100)       | 530 (77)          | 617 (89)                   | 452 (66)                      | 525 (76)        | 361 (52)     |
|  | <b>Maximum</b>                                      | 783 (114)       | 603 (87)          | 658 (95)                   | 482 (70)                      | 612 (89)        | 421 (61)     |
|  | <b>Standard Deviation MPa (ksi)</b>                 | 34 (5)          | 26 (4)            | 17 (2)                     | 13 (2)                        | 40 (6)          | 28 (4)       |
|  | <b>Number Specimens</b>                             | 5               | 5                 | 5                          | 5                             | 4               | 4            |
| <b>Flexure Modulus</b><br>( $E_{11}$ )       | <b>Mean GPa (msi)</b>                               | 104.4 (15.1)    | 80.4 (11.7)       | 98.1 (14.2)                | 71.8 (10.4)                   | 155.7 (22.6)    | 107.1 (15.5) |
|  | <b>Minimum</b>                                      | 100.4 (14.6)    | 77.3 (11.2)       | 94.8 (13.7)                | 69.4 (10.1)                   | 141.3 (20.5)    | 116.8 (16.9) |
|  | <b>Maximum</b>                                      | 107.7 (15.6)    | 82.9 (12.0)       | 100.4 (14.6)               | 73.5 (10.7)                   | 169.8 (24.6)    | 97.2 (14.1)  |
|  | <b>Standard Deviation GPa (msi)</b>                 | 2.8 (0.4)       | 2.2 (0.3)         | 2.2 (0.3)                  | 1.6 (0.2)                     | 13.2 (1.9)      | 9.1 (1.3)    |
|  | <b>Number Specimens</b>                             | 5               | 5                 | 5                          | 5                             | 4               | 4            |
| <b>Peak Strain</b><br>( $\epsilon_{11}$ )    | <b>Mean (%)</b>                                     | NA              | 0.927             | NA                         | 1.111                         | NA              | 0.587        |
|  | <b>Minimum</b>                                      |                 | 0.871             |                            | 0.910                         |                 | 0.504        |
|  | <b>Maximum</b>                                      |                 | 0.999             |                            | 1.295                         |                 | 0.659        |
|  | <b>Standard Deviation (%)</b>                       |                 | 0.049             |                            | 0.137                         |                 | 0.069        |
|  | <b>Number Specimens</b>                             |                 | 5                 |                            | 5                             |                 | 4            |

Table 3: Autoclaved 90° Flexure Strength and Modulus

|                                |   |          |                    |          |             |          |            |                   |            |
|--------------------------------|---|----------|--------------------|----------|-------------|----------|------------|-------------------|------------|
| Material:                      | K6356U / 30% Alum. Filled / 862W            |          |                    |          |             |          |            |                   |            |
|                                |   |          |                    |          |             |          |            |                   |            |
| Matrix Content:                | 62.91                                       | % (w/w)  | Composite Density: |          |             | 1.704    |            | g/cm <sup>3</sup> |            |
| Fiber Volume:                  | 37.10                                       | %        | FAW:               |          |             | 154.00   |            | gsm               |            |
| Ply Thickness:                 | 0.0078                                      | inches   |                    |          |             |          |            |                   |            |
|                                |   |          |                    |          |             |          |            |                   |            |
| Test Method:                   | ASTM D790: 90°-Flexure Strength and Modulus |          |                    |          |             |          |            |                   |            |
| Normalization:                 | NA  |          |                    |          |             |          |            |                   |            |
|                                |   |          |                    |          |             |          |            |                   |            |
| Test Temperature (°F)          | RT  |          | RT                 |          | 250         |          | 250        |                   |            |
| Moisture Saturation (%)        | 0.0   |          | 0.283              |          | 0.0         |          | 0.283      |                   |            |
| Environmental Conditioning     | Dry   |          | Wet                |          | Dry         |          | Wet        |                   |            |
| Mechanical Property            | Normalized                                  | Measured | Normalized         | Measured | Normalized  | Measured | Normalized | Measured          |            |
| Flexure Strength $\sigma_{11}$ | Mean MPa (ksi)                              | NA       | 30.4 (4.4)         | NA       | 37.8 (5.5)  | NA       | 36.1 (5.2) | NA                | 23.6 (3.4) |
|                                | Minimum                                     | NA       | 28.4 (4.1)         | NA       | 33.2 (4.8)  | NA       | 25.2 (3.7) | NA                | 21.2 (3.1) |
|                                | Maximum                                     | NA       | 36.4 (5.3)         | NA       | 43.9 (6.4)  | NA       | 45.2 (6.6) | NA                | 25.9 (3.8) |
|                                | Standard Deviation MPa (ksi)                | NA       | 3.4 (0.5)          | NA       | 5.0 (0.7)   | NA       | 7.7 (1.1)  | NA                | 2.2 (0.3)  |
|                                | Number Specimens                            | NA       | 5                  | NA       | 5           | NA       | 5          | NA                | 5          |
| Flexure Modulus $E_{11}$       | Mean GPa (msi)                              | NA       | 4.68 (0.68)        | NA       | 4.98 (0.72) | NA       | Noisy      | NA                | Noisy      |
|                                | Minimum                                     | NA       | 4.53 (0.66)        | NA       | 4.83 (0.70) | NA       |            | NA                |            |
|                                | Maximum                                     | NA       | 4.88 (0.71)        | NA       | 5.20 (0.75) | NA       |            | NA                |            |
|                                | Standard Deviation (GPa)                    | NA       | 0.13 (0.02)        | NA       | 0.15 (0.02) | NA       |            | NA                |            |
|                                | Number Specimens                            | 5        | 5                  | NA       | 5           | NA       |            | NA                |            |
| Peak Strain $\epsilon_{11}$    | Mean  | NA       | 0.657              | NA       | 0.841       | NA       | 0.964      | NA                | Noisy      |
|                                | Minimum                                     | NA       | 0.603              | NA       | 0.703       | NA       | 0.710      | NA                |            |
|                                | Maximum                                     | NA       | 0.811              | NA       | 0.992       | NA       | 1.230      | NA                |            |
|                                | Standard Deviation (%)                      | NA       | 0.087              | NA       | 0.118       | NA       | 0.224      | NA                |            |
|                                | Number Specimens                            | NA       | 5                  | NA       | 5           | NA       | 5          | NA                |            |

Table 4: Compression Molded 90° Flexure Strength and Modulus

|  |   |                 |                   |                            |                               |                 |                |
|--|---|-----------------|-------------------|----------------------------|-------------------------------|-----------------|----------------|
| <b>Material:</b>                                   | K6356U / 30% Alum. Filled / 862W Compression Molded |                 |                   |                            |                               |                 |                |
|  |   |                 |                   |                            |                               |                 |                |
| <b>Matrix Content:</b>                             | 62.91 (1-3)   | % (w/w)         |                   | <b>Composite Density:</b>  | 1.782 (1) 1.834 (2) 1.839 (3) | <b>g/cc</b>     |                |
| <b>Fiber Volume:</b>                               | 38.50 (1) 34.40 (2) 36.60 (3)                       | %               |                   | <b>Fiber Areal Weight:</b> | 154.00 (1-3)                  | <b>gsm</b>      |                |
| <b>Ply Thickness:</b>                              | 0.0072 (1) 0.0084 (2) 0.0079 (3)                    | <b>inches</b>   |                   |                            |                               |                 |                |
|  |   |                 |                   |                            |                               |                 |                |
| <b>Test Method:</b>                                | ASTM D790: 90°-Flexure Strength and Modulus         |                 |                   |                            |                               |                 |                |
| <b>Normalization:</b>                              | NA  |                 |                   |                            |                               |                 |                |
|  |   |                 |                   |                            |                               |                 |                |
| <b>Test Temperature (°F)</b>                       | CMP-1 RT  |                 | CMP-3 RT          |                            | CMP-2 250                     |                 |                |
| <b>Moisture Saturation (%)</b>                     | 0.0   |                 | 0.212             |                            | 0.0                           |                 |                |
| <b>Environmental Conditioning</b>                  | Dry   |                 | Wet               |                            | Dry                           |                 |                |
| <b>Mechanical Property</b>                         | <b>Normalized</b>                                   | <b>Measured</b> | <b>Normalized</b> | <b>Measured</b>            | <b>Normalized</b>             | <b>Measured</b> |                |
| <b>Flexure Strength (<math>\sigma_{11}</math>)</b> | <b>Mean MPa (ksi)</b>                               | NA              | 33.07 (4.80)      | NA                         | 38.90 (5.64)                  | NA              | 25.37 (3.68)   |
|  | <b>Minimum</b>                                      |                 | 30.27 (4.39)      |                            | 36.63 (5.31)                  |                 | 23.98 (3.48)   |
|  | <b>Maximum</b>                                      |                 | 37.45 (5.43)      |                            | 40.69 (5.90)                  |                 | 26.66 (3.87)   |
|  | <b>Standard Deviation MPa (ksi)</b>                 |                 | 3.22 (0.47)       |                            | 1.51 (0.22)                   |                 | 1.35 (0.20)    |
|  | <b>Number Specimens</b>                             |                 | 5                 |                            | 5                             |                 | 3              |
| <b>Flexure Modulus (<math>E_{11}</math>)</b>       | <b>Mean MPa (ksi)</b>                               |                 | 3936.9 (570.9)    |                            | 4754.5 (689.4)                |                 | 3294.8 (477.7) |
|  | <b>Minimum</b>                                      |                 | 3801.2 (551.2)    |                            | 4687.1 (679.6)                |                 | 3080.5 (446.7) |
|  | <b>Maximum</b>                                      |                 | 4037.4 (585.4)    |                            | 4830.3 (700.4)                |                 | 3561.6 (516.4) |
|  | <b>Standard Deviation MPa (ksi)</b>                 |                 | 87.5 (12.7)       |                            | 53.9 (7.8)                    |                 | 244.8 (35.5)   |
|  | <b>Number Specimens</b>                             |                 | 5                 |                            | 5                             |                 | 3              |
| <b>Peak Strain (<math>\epsilon_{11}</math>)</b>    | <b>Mean (%)</b>                                     |                 | 0.892             |                            | 0.898                         |                 | 0.801          |
|  | <b>Minimum</b>                                      |                 | 0.787             |                            | 0.853                         |                 | 0.740          |
|  | <b>Maximum</b>                                      |                 | 1.011             |                            | 0.925                         |                 | 0.898          |
|  | <b>Standard Deviation (%)</b>                       |                 | 0.091             |                            | 0.028                         |                 | 0.085          |
|  | <b>Number Specimens</b>                             |                 | 5                 |                            | 5                             |                 | 3              |

Table 5: Autoclaved Short Beam Shear Strength

|  |   |               |               |                            |                                |
|--|---|---------------|---------------|----------------------------|--------------------------------|
| <b>Material:</b>   | K6356U / 30% Alum. Filled / 862W                        |               |               |                            |                                |
|  |   |               |               |                            |                                |
| <b>Matrix Content:</b>                                   | 62.91   | % (w/w)       |               | <b>Composite Density:</b>  | 1.7690 <b>g/cm<sup>3</sup></b> |
| <b>Fiber Volume:</b>                                     | 37.10   | %             |               | <b>Fiber Areal Weight:</b> | 154.0 <b>gsm</b>               |
| <b>Ply Thickness:</b>                                    | 0.0078  | inches        |               |                            |                                |
|  |   |               |               |                            |                                |
| <b>Test Method:</b>                                      | ASTM D2344: Short Beam Shear Strength [0] <sub>16</sub> |               |               |                            |                                |
| <b>Normalization:</b>                                    | NA  |               |               |                            |                                |
|  |   |               |               |                            |                                |
| <b>Test Temperature (°F)</b>                             |   | RT            | RT            | 250                        | 250                            |
| <b>Moisture Saturation (%)</b>                           |   | 0.0           | 0.309         | 0                          | 0.309                          |
| <b>Environmental Conditioning</b>                        |   | Dry           | Wet           | Dry                        | Wet                            |
| <b>Mechanical Property</b>                               |   | Measured      | Measured      | Measured                   | Measured                       |
| <b>SHORT BEAM<br/>SHEAR<br/>STRENGTH (S<sub>H</sub>)</b> | <b>Mean MPa<br/>(ksi)</b>                               | 42.4<br>(6.1) | 39.4<br>(5.7) | 20.2<br>(2.9)              | 20.0<br>(2.9)                  |
|  | <b>Minimum</b>  | 40.5<br>(5.9) | 36.3<br>(5.3) | 19.2<br>(2.8)              | 17.5<br>(2.5)                  |
|  | <b>Maximum</b>  | 44.1<br>(6.4) | 41.0<br>(5.9) | 20.5<br>(3.0)              | 22.3<br>(3.2)                  |
|  | <b>Standard<br/>Deviation MPa<br/>(ksi)</b>             | 1.3<br>(0.2)  | 2.0<br>(0.3)  | 0.6<br>(.09)               | 1.9<br>(0.28)                  |
|  | <b>Number<br/>Specimens</b>                             | 5             | 5             | 5                          | 5                              |



Table 6: Compression Molded Short Beam Shear Strength

|  |   |                 |                   |                            |                               |                 |              |
|--|---|-----------------|-------------------|----------------------------|-------------------------------|-----------------|--------------|
| <b>Material:</b>                             | K6356U / 30% Alum. Filled / 862W Compression Molded |                 |                   |                            |                               |                 |              |
|  |   |                 |                   |                            |                               |                 |              |
| <b>Matrix Content:</b>                       | 62.91 (1-3)   | <b>% (w/w)</b>  |                   | <b>Composite Density:</b>  | 1.782 (1) 1.834 (2) 1.839 (3) | <b>g/cc</b>     |              |
| <b>Fiber Volume:</b>                         | 38.50 (1) 34.40 (2) 36.60 (3)                       | <b>%</b>        |                   | <b>Fiber Areal Weight:</b> | 154.0 (1-3)                   | <b>gsm</b>      |              |
| <b>Ply Thickness:</b>                        | 0.0072 (1) 0.0084 (2) 0.0079 (3)                    | <b>inches</b>   |                   |                            |                               |                 |              |
|  |   |                 |                   |                            |                               |                 |              |
| <b>Test Method:</b>                          | ASTM D2234: Short Beam Shear Properties             |                 |                   |                            |                               |                 |              |
| <b>Normalization:</b>                        | NA  |                 |                   |                            |                               |                 |              |
|  |   |                 |                   |                            |                               |                 |              |
| <b>ID and Test Temperature (°F)</b>          | CMP-1 RT  |                 | CMP-3 RT          |                            | CMP-2 250                     |                 |              |
| <b>Moisture Saturation (%)</b>               | 0.0   |                 | 0.212             |                            | 0.0                           |                 |              |
| <b>Environmental Conditioning</b>            | Dry   |                 | Wet               |                            | Dry                           |                 |              |
| <b>Mechanical Property</b>                   | <b>Normalized</b>                                   | <b>Measured</b> | <b>Normalized</b> | <b>Measured</b>            | <b>Normalized</b>             | <b>Measured</b> |              |
| <b>SBS Shear Strength (<math>S_h</math>)</b> | <b>Mean MPa (ksi)</b>                               | NA              | 47.07 (6.83)      | NA                         | 45.77 (6.64)                  | NA              | 20.05 (2.91) |
|  | <b>Minimum</b>                                      |                 | 45.34 (6.57)      |                            | 44.35 (6.43)                  |                 | 18.66 (2.71) |
|  | <b>Maximum</b>                                      |                 | 48.41 (7.02)      |                            | 47.86 (6.94)                  |                 | 21.25 (3.08) |
|  | <b>Standard Deviation MPa (ksi)</b>                 |                 | 1.17 (0.17)       |                            | 1.63 (0.24)                   |                 | 0.99 (0.14)  |
|  | <b>Number Specimens</b>                             |                 | 5                 |                            | 5                             |                 | 5            |

Table 7: Autoclaved Compression Strength

|                                    |  |            |            |                     |            |                   |            |            |            |
|------------------------------------|--|------------|------------|---------------------|------------|-------------------|------------|------------|------------|
| Material:                          | K6356U / 30% Alum. Filled / 862W                 |            |            |                     |            |                   |            |            |            |
|                                    |  |            |            |                     |            |                   |            |            |            |
| Matrix Content:                    | 62.91  | % (w/w)    |            | Composite Density:  | 1.769      | g/cm <sup>3</sup> |            |            |            |
| Fiber Volume:                      | 37.10  | %          |            | Fiber Areal Weight: | 154.0      | gsm               |            |            |            |
| Ply Thickness:                     | 0.0078   | inches     |            |                     |            |                   |            |            |            |
|                                    |  |            |            |                     |            |                   |            |            |            |
| Test Method:                       | ASTM D695 Compression Strength [0] <sub>16</sub> |            |            |                     |            |                   |            |            |            |
| Normalization:                     | Normalize to 50% Fiber volume                    |            |            |                     |            |                   |            |            |            |
|                                    |  |            |            |                     |            |                   |            |            |            |
| Test Temperature (°F)              | RT   |            | RT         |                     | 250        |                   | 250        |            |            |
| Moisture Saturation (%)            | 0.0  |            | 0.321      |                     | 0.0        |                   | 0.321      |            |            |
| Environmental Conditioning         | Dry  |            | Wet        |                     | Dry        |                   | Wet        |            |            |
| Mechanical Property                | Normalized                                       | Measured   | Normalized | Measured            | Normalized | Measured          | Normalized | Measured   |            |
| Compression Strength $\sigma_{11}$ | Mean MPa (ksi)                                   | 331 (48.0) | 246 (35.7) | 311 (45.1)          | 231 (33.5) | 299 (43.4)        | 222 (32.2) | 157 (22.8) | 117 (17.0) |
|                                    | Minimum  | 315 (45.7) | 234 (33.9) | 303 (43.9)          | 225 (32.6) | 285               | 211 (30.6) | 135 (19.6) | 100 (14.5) |
|                                    | Maximum  | 366 (53.1) | 272 (39.4) | 321 (46.5)          | 238 (34.5) | 314 (45.5)        | 233 (33.8) | 195 (28.3) | 120 (17.4) |
|                                    | Standard Deviation MPa (ksi)                     | 20 (2.9)   | 15 (2.2)   | 8 (1.2)             | 6 (0.87)   | 11 (1.6)          | 8 (1.2)    | 23 (3.3)   | 17 (2.5)   |
|                                    | Number Specimens                                 | 5          | 5          | 5                   | 5          | 5                 | 5          | 5          | 5          |

Table 8: Compression Molded Compression Strength

|  |  |                   |                   |                            |                                  |                   |                   |
|--|--|-------------------|-------------------|----------------------------|----------------------------------|-------------------|-------------------|
| <b>Material:</b>                                       | K6356U / 30% Alum. Filled / 862W Compression Molded          |                   |                   |                            |                                  |                   |                   |
|  |  |                   |                   |                            |                                  |                   |                   |
| <b>Matrix Content:</b>                                 | 62.91 (1-3)  | <b>% (w/w)</b>    |                   | <b>Composite Density:</b>  | 1.782 (1) 1.834<br>(2) 1.839 (3) | <b>g/cc</b>       |                   |
| <b>Fiber Volume:</b>                                   | 38.50 (1) 34.40 (2)<br>36.60 (3)                             | <b>%</b>          |                   | <b>Fiber Areal Weight:</b> | 154.0 (1-3)                      | <b>gsm</b>        |                   |
| <b>Ply Thickness:</b>                                  | 0.0072 (1) 0.0084 (2)<br>0.0079 (3)                          | <b>inches</b>     |                   |                            |                                  |                   |                   |
|  |  |                   |                   |                            |                                  |                   |                   |
| <b>Test Method:</b>                                    | ASTM D695: Compression Strength Properties [0] <sub>16</sub> |                   |                   |                            |                                  |                   |                   |
| <b>Normalization:</b>                                  | NA   |                   |                   |                            |                                  |                   |                   |
|  |  |                   |                   |                            |                                  |                   |                   |
| <b>Test Temperature (°F)</b>                           | CMP-1 RT   |                   | CMP-3 RT          |                            | CMP-2 250                        |                   |                   |
| <b>Moisture Saturation (%)</b>                         | 0.0  |                   | 0.212             |                            | 0.0                              |                   |                   |
| <b>Environmental Conditioning</b>                      | Dry  |                   | Wet               |                            | Dry                              |                   |                   |
|  |  | <b>Normalized</b> | <b>Measured</b>   | <b>Normalized</b>          | <b>Measured</b>                  | <b>Normalized</b> | <b>Measured</b>   |
| <b>Compression Strength (<math>\sigma_{11}</math>)</b> | <b>Mean MPa (ksi)</b>  | 373.58<br>(54.17) | 287.66<br>(41.71) | 317.36<br>(46.02)          | 232.31<br>(33.68)                | 275.42<br>(39.94) | 189.49<br>(27.48) |
|  | <b>Minimum</b>   | 351.39<br>(50.95) | 270.57<br>(39.23) | 284.69<br>(41.28)          | 208.39<br>(30.22)                | 272.65<br>(39.53) | 187.58<br>(27.20) |
|  | <b>Maximum</b>   | 402.40<br>(58.35) | 309.85<br>(44.93) | 336.53<br>(48.80)          | 246.34<br>(35.72)                | 278.20<br>(40.34) | 191.40<br>(27.75) |
|  | <b>Standard Deviation MPa (ksi)</b>                          | 20.22<br>(2.93)   | 15.57<br>(2.26)   | 19.92<br>(2.89)            | 14.58<br>(2.11)                  | 3.93<br>(0.57)    | 2.70<br>(0.39)    |
|  | <b>Number Specimens</b>                                      | 5                 | 5                 | 5                          | 5                                | 2                 | 2                 |

Table 9: Autoclaved 0° Tensile Strength and Modulus

| Material:                                    |                              | K6356U / 30% Alum. Filled / 862W                   |                |                     |          |            |                   |            |          |
|--|------------------------------|--|----------------|---------------------|----------|------------|-------------------|------------|----------|
|  |                              |  |                |                     |          |            |                   |            |          |
| Matrix Content:                              |                              | 62.91  | % (w/w)        | Composite Density:  |          | 1.845      | g/cm <sup>3</sup> |            |          |
| Fiber Volume:                                |                              | 34.50  | %              | Fiber Areal Weight: |          | 154.0      | gsm               |            |          |
| Ply Thickness:                               |                              | 0.0084   | inches         |                     |          |            |                   |            |          |
|  |                              |  |                |                     |          |            |                   |            |          |
| Test Method:                                 |                              | ASTM D3039: 0-Tension and Modulus [0] <sub>5</sub> |                |                     |          |            |                   |            |          |
| Normalization:                               |                              | Normalize to 50% fiber volume                      |                |                     |          |            |                   |            |          |
|  |                              |  |                |                     |          |            |                   |            |          |
| Test Temperature (°F)                        |                              | RT ONLY  |                | RT                  |          | 250        |                   | 250        |          |
| Moisture Saturation (%)                      |                              | NA   |                | 0                   |          | 0          |                   | 0          |          |
| Environmental Conditioning                   |                              | Dry  |                | Wet                 |          | Dry        |                   | Wet        |          |
| Mechanical Property                          |                              | Normalized   | Measured       | Normalized          | Measured | Normalized | Measured          | Normalized | Measured |
| Ultimate Tensile Strength (σ <sub>11</sub> ) | Mean MPa (ksi)               | 1645.6 (238.6)                                     | 1135.5 (164.6) |                     |          |            |                   |            |          |
|  | Minimum                      | 1549.1 (224.6)                                     | 1068.9 (155.0) |                     |          |            |                   |            |          |
|  | Maximum                      | 1750.1 (253.8)                                     | 1207.6 (175.1) |                     |          |            |                   |            |          |
|  | Standard Deviation MPa (ksi) | 89.8 (13.0)  | 61.9 (9.0)     |                     |          |            |                   |            |          |
|  | Number Specimens             | 6  | 6              |                     |          |            |                   |            |          |
| Tensile Modulus (E <sub>11</sub> )           | Mean GPa (msi)               | 304.9 (44.2)                                       | 210.4 (30.5)   |                     |          |            |                   |            |          |
|  | Minimum                      | 286.5 (41.5)                                       | 197.7 (28.7)   |                     |          |            |                   |            |          |
|  | Maximum                      | 322.6 (46.8)                                       | 222.6 (32.3)   |                     |          |            |                   |            |          |
|  | Standard Deviation GPa (msi) | 14.2 (2.1)   | 9.8 (1.4)      |                     |          |            |                   |            |          |
|  | Number Specimens             | 6  | 6              |                     |          |            |                   |            |          |
| Poisson's Ratio (ν <sub>12</sub> )           | Mean                         | NA   | 0.3562         |                     |          |            |                   |            |          |
|  | Minimum                      |  | 0.3150         |                     |          |            |                   |            |          |
|  | Maximum                      |  | 0.3920         |                     |          |            |                   |            |          |
|  | Standard Deviation           |  | 0.0282         |                     |          |            |                   |            |          |
|  | Number Specimens             |  | 6              |                     |          |            |                   |            |          |
| Peak Strain (ε <sub>11</sub> )               | Mean (%)                     | NA   | 0.53           |                     |          |            |                   |            |          |
|  | Minimum                      |  | 0.51           |                     |          |            |                   |            |          |
|  | Maximum                      |  | 0.56           |                     |          |            |                   |            |          |
|  | Standard Deviation (%)       |  | 0.0002         |                     |          |            |                   |            |          |
|  | Number Specimens             |  | 6              |                     |          |            |                   |            |          |

Table 10: Autoclaved 90° Tensile Strength and Modulus

|  |                          |   |                 |            |                 |            |                 |            |                 |       |
|--|--------------------------|---|-----------------|------------|-----------------|------------|-----------------|------------|-----------------|-------|
| Material:                              |                          | K6356U / 30% Alum. Filled / 862W                              |                 |            |                 |            |                 |            |                 |       |
|  |                          |   |                 |            |                 |            |                 |            |                 |       |
| Matrix Content:                        |                          | 62.91   | % (w/w)         |            | Density:        |            | 1.7630          |            |                 | g/cm³ |
| Fiber Volume:                          |                          | 37.70   | %               |            | FAW:            |            | 154.0           |            |                 | gsm   |
| Ply Thickness:                         |                          | 0.0077  | inches          |            |                 |            |                 |            |                 |       |
|  |                          |   |                 |            |                 |            |                 |            |                 |       |
| Test Method:                           |                          | ASTM D3039: 90°Tension Strength and Modulus [0] <sub>10</sub> |                 |            |                 |            |                 |            |                 |       |
| Normalization:                         |                          | NA  |                 |            |                 |            |                 |            |                 |       |
|  |                          |   |                 |            |                 |            |                 |            |                 |       |
| Test Temperature (°F)                  |                          | RT  |                 | RT         |                 | 250        |                 | 250        |                 |       |
| Moisture Saturation (%)                |                          | 0.0   |                 | 0.266      |                 | 0.0        |                 | 0.266      |                 |       |
| Environmental Conditioning             |                          | None  |                 | Wet        |                 | None       |                 | Wet        |                 |       |
| Mechanical Property                    |                          | Normalized  | Measured        | Normalized | Measured        | Normalized | Measured        | Normalized | Measured        |       |
| Tensile Strength<br>(σ <sub>11</sub> ) | Mean (MPa)               | NA  | 19.89<br>(2.88) | NA         | 17.92<br>(2.60) | NA         | 11.15<br>(1.62) | NA         | 9.17<br>(1.33)  |       |
|  | Minimum                  |   | 19.88<br>(2.88) |            | NA              |            | 8.98<br>(1.30)  |            | 8.20<br>(1.19)  |       |
|  | Maximum                  |   | 19.90<br>(2.89) |            | NA              |            | 14.35<br>(2.08) |            | 10.31<br>(1.49) |       |
|  | Standard Deviation (MPa) |   | 0.02<br>(0.003) |            | 0.0             |            | 2.83<br>(0.41)  |            | 1.06<br>(0.15)  |       |
|  | Number Specimens         |   | 2               |            | 1               |            | 3               |            | 3               |       |
| Tensile Modulus<br>(E <sub>11</sub> )  | Mean (GPa)               | NA  | 6.81<br>(0.99)  | NA         | 7.21<br>(1.05)  | NA         | 4.38<br>(0.64)  | NA         | 3.43<br>(0.50)  |       |
|  | Minimum                  |   | 6.80<br>(0.99)  |            | NA              |            | 4.01<br>(0.58)  |            | 3.68<br>(0.53)  |       |
|  | Maximum                  |   | 6.82<br>(0.99)  |            | NA              |            | 5.01<br>(0.73)  |            | 3.21<br>(0.47)  |       |
|  | Standard Deviation (GPa) |   | 0.01<br>(0.002) |            | 0.0             |            | 0.55<br>(0.08)  |            | 0.23<br>(0.03)  |       |
|  | Number Specimens         |   | 2               |            | 1               |            | 3               |            | 3               |       |
| Poisson's Ratio<br>(ν <sub>12</sub> )  | Mean                     | NA  | 0.021           | NA         | 0.015           | NA         | 0.027           | NA         | 0.0052          |       |
|  | Minimum                  |   | 0.017           |            | NA              |            | 0.021           |            | 0.0054          |       |
|  | Maximum                  |   | 0.024           |            | NA              |            | 0.038           |            | 0.0051          |       |
|  | Standard Deviation       |   | 0.005           |            | 0.00            |            | 0.009           |            | 0.0002          |       |
|  | Number Specimens         |   | 2               |            | 1               |            | 3               |            | 3               |       |
| Peak Strain<br>(ε <sub>11</sub> )      | Mean (%)                 | NA  | 0.280           | NA         | 0.253           | NA         | (Noisy)         | NA         | 0.409           |       |
|  | Minimum                  |   | 0.229           |            | NA              |            |                 |            | 0.386           |       |
|  | Maximum                  |   | 0.330           |            | NA              |            |                 |            | 0.441           |       |
|  | Standard Deviation (%)   |   | 0.071           |            | 0.00            |            |                 |            | 0.028           |       |
|  | Number Specimens         |   | 2               |            | 1               |            |                 |            | 3               |       |

Table 11: Autoclaved Northrop Grumman Open-Hole Compression Strength

|  |                              |  |          |            |                    |            |          |            |          |                   |
|--|------------------------------|--|----------|------------|--------------------|------------|----------|------------|----------|-------------------|
| Material:                                    |                              | K6356U / 30% Alum. Filled / 862W Prepreg Autoclaved                    |          |            |                    |            |          |            |          |                   |
|  |                              |  |          |            |                    |            |          |            |          |                   |
| Resin Content:                               |                              | 65.92  | % (w/w)  |            | Composite Density: |            | 1.7780   |            |          | g/cm <sup>3</sup> |
| Fiber Volume:                                |                              | 35.10  | %        |            | FAW:               |            | 154.0    |            |          | gsm               |
| Ply Thickness:                               |                              | 0.0081   | inches   |            |                    |            |          |            |          |                   |
|  |                              |  |          |            |                    |            |          |            |          |                   |
| Test Method:                                 |                              | Northrop Grumman: Open-Hole Compression [45, 0, -45, 90] <sub>3s</sub> |          |            |                    |            |          |            |          |                   |
| Normalization:                               |                              | Normalize to 50% fiber volume  |          |            |                    |            |          |            |          |                   |
|  |                              |  |          |            |                    |            |          |            |          |                   |
| Test Temperature (°F)                        |                              | 75   |          | 75         |                    | 250        |          | 250        |          |                   |
| Moisture Saturation (%)                      |                              | 0.0  |          | 0.120      |                    | 0.0        |          | 0.120      |          |                   |
| Environmental Conditioning                   |                              | None   |          | Wet        |                    | None       |          | Wet        |          |                   |
| Mechanical Property                          |                              | Normalized   | Measured | Normalized | Measured           | Normalized | Measured | Normalized | Measured |                   |
| Open Hole Compression Strength $\sigma_{11}$ | Mean MPa (ksi)               | 145 (21)   | 102 (15) | 141 (20)   | 99 (14)            | 108 (16)   | 76 (11)  | 104 (15)   | 73 (11)  |                   |
|  | Minimum                      | 140 (20)   | 98 (14)  | 130 (19)   | 91 (13)            | 93 (13)    | 65 (9)   | 100 (15)   | 75 (11)  |                   |
|  | Maximum                      | 151 (22)   | 106 (15) | 148 (21)   | 104 (15)           | 117 (17)   | 82 (12)  | 107 (16)   | 71 (10)  |                   |
|  | Standard Deviation MPa (ksi) | 5 (0.7)  | 4 (0.6)  | 7 (1.0)    | 5 (0.7)            | 9 (1.3)    | 6 (0.9)  | 3 (0.4)    | 2 (0.3)  |                   |
|  | Number Specimens             | 5  | 5        | 5          | 5                  | 5          | 5        | 5          | 5        |                   |

Table 12: Autoclaved In-Plane Shear Strength and Modulus

|   |  |                 |                   |                            |                   |                   |                   |                 |                |
|---|--|-----------------|-------------------|----------------------------|-------------------|-------------------|-------------------|-----------------|----------------|
| <b>Material:</b>  | K6356U / 30% Alum. Filled / 862W Prepreg, Autoclaved                             |                 |                   |                            |                   |                   |                   |                 |                |
| <b>Matrix Content:</b>  | 62.91  | % (w/w)         |                   | <b>Composite Density:</b>  | 1.716             | g/cm <sup>3</sup> |                   |                 |                |
| <b>Fiber Volume:</b>  | 32.60  | %               |                   | <b>Fiber Areal Weight:</b> | 147.0             | gsm               |                   |                 |                |
| <b>Ply Thickness:</b>   | 0.0085   | inches          |                   |                            |                   |                   |                   |                 |                |
| <b>Test Method:</b>   | ASTM D3518: In-Plane Shear Strength and Modulus [45, -45, -45, 45] <sub>2s</sub> |                 |                   |                            |                   |                   |                   |                 |                |
| <b>Normalization:</b>   | NA   |                 |                   |                            |                   |                   |                   |                 |                |
| <b>Test Temperature (°F)</b>  | RT   |                 | RT                |                            | 250               |                   | 250               |                 |                |
| <b>Moisture Saturation (%)</b>  | NA   |                 | 0.429             |                            | NA                |                   | 0.429             |                 |                |
| <b>Environmental Conditioning</b>   | Dry  |                 | Wet               |                            | Dry               |                   | Wet               |                 |                |
| <b>Mechanical Property</b>  | <b>Normalized</b>  | <b>Measured</b> | <b>Normalized</b> | <b>Measured</b>            | <b>Normalized</b> | <b>Measured</b>   | <b>Normalized</b> | <b>Measured</b> |                |
| <b>Maximum Shear Stress (<math>\tau_{12}</math>)</b>                            | <b>Mean MPa (ksi)</b>  | NA              | 35.69 (5.18)      | NA                         | 35.14 (5.10)      | NA                | 19.67 (2.85)      | NA              | 20.35 (2.95)   |
|   | <b>Minimum</b>   |                 | 31.04 (4.50)      |                            | 32.44 (4.70)      |                   | 16.24 (2.35)      |                 | 19.18 (2.78)   |
|   | <b>Maximum</b>   |                 | 40.78 (5.91)      |                            | 37.90 (5.50)      |                   | 23.88 (3.46)      |                 | 21.05 (3.05)   |
|   | <b>Standard Deviation MPa (ksi)</b>  |                 | 4.46 (0.65)       |                            | 1.99 (0.29)       |                   | 3.11 (0.45)       |                 | 0.73 (0.11)    |
|   | <b>Number Specimens</b>  |                 | 5                 |                            | 4                 |                   | 5                 |                 | 5              |
| <b>Chord Shear Modulus (<math>G_{12}</math>)</b>                                | <b>Mean MPa (ksi)</b>  |                 | 3201.7 (464.2)    |                            | 3090.8 (448.2)    |                   | 1827.8 (265.0)    |                 | 1584.1 (229.7) |
|   | <b>Minimum</b>   |                 | NA                |                            | 2904.5 (421.2)    |                   | 1623.8 (235.5)    |                 | 1413.7 (205.0) |
|   | <b>Maximum</b>   |                 | NA                |                            | 3230.8 (468.5)    |                   | 1939.2 (281.2)    |                 | 1706.0 (247.4) |
|   | <b>Standard Deviation MPa (ksi)</b>  |                 | 0.0               |                            | 145.7 (21.1)      |                   | 126.3 (18.3)      |                 | 118.1 (17.1)   |
|   | <b>Number Specimens</b>  |                 | 1                 |                            | 4                 |                   | 5                 |                 | 5              |
| <b>Shear Stress at 5% Shear Strain (<math>\tau_{12}</math>) (if applicable)</b> | <b>Mean</b>  |                 | NA                |                            | NA                |                   | 13.64 (1.98)      |                 | 16.17 (2.34)   |
|   | <b>Minimum</b>   |                 |                   |                            |                   |                   | 11.71 (1.70)      |                 | 14.69 (2.13)   |
|   | <b>Maximum</b>   |                 |                   |                            |                   |                   | 17.54 (2.54)      |                 | 17.46 (2.53)   |
|   | <b>Standard Deviation</b>  |                 |                   |                            |                   |                   | 2.35 (0.34)       |                 | 1.17 (0.17)    |
|   | <b>Number Specimens</b>  |                 |                   |                            |                   |                   | 5                 |                 | 5              |

Table 13: Autoclaved Compression after Impact Strength

|   |   |                |                |                     |                |                 |                   |                 |               |
|---|---|----------------|----------------|---------------------|----------------|-----------------|-------------------|-----------------|---------------|
| Material:   | K6356U / 30% Alum. Filled / 862W Prepreg, Autoclaved                        |                |                |                     |                |                 |                   |                 |               |
|   |   |                |                |                     |                |                 |                   |                 |               |
| Matrix Content:                                     | 65.92   | % (w/w)        |                | Composite Density:  |                | 1.775           | g/cm <sup>3</sup> |                 |               |
| Fiber Volume:                                       | 35.50   | %              |                | Fiber Areal Weight: |                | 147.0           | %                 |                 |               |
| Ply Thickness:                                      | 0.0078  | inches         |                |                     |                |                 |                   |                 |               |
|   |   |                |                |                     |                |                 |                   |                 |               |
| Test Method:  | ASTM D7137 Compression after Impact Strength [45, 0, -45, 90] <sub>3s</sub> |                |                |                     |                |                 |                   |                 |               |
| Normalization:                                      | Normalize to 50% Fiber volume   |                |                |                     |                |                 |                   |                 |               |
|   |   |                |                |                     |                |                 |                   |                 |               |
| Test Temperature (°F)                               |   | DRY-CONTROL-RT |                | WET-CONTROL-RT      |                | Impacted-DRY-RT |                   | Impacted-WET-RT |               |
| Moisture Saturation (%)                             |   | 0.0            |                | 0.202               |                | 0.0             |                   | 0.202           |               |
| Environmental Conditioning                          |   | Dry            |                | Wet                 |                | Dry             |                   | Wet             |               |
| Mechanical Property                                 |   | Normalized     | Measured       | Normalized          | Measured       | Normalized      | Measured          | Normalized      | Measured      |
| Compression after Impact Strength ( $\sigma_{11}$ ) | Mean MPa (ksi)  | 148.57 (21.54) | 105.48 (15.29) | 159.21 (23.09)      | 113.04 (16.39) | 135.34 (19.62)  | 96.09 (13.93)     | 128.33 (18.61)  | 91.11 (13.21) |
|   | Minimum   | NA             | NA             | NA                  | NA             | NA              | NA                | NA              | NA            |
|   | Maximum   | NA             | NA             | NA                  | NA             | NA              | NA                | NA              | NA            |
|   | Standard Deviation MPa (ksi)  | NA             | NA             | NA                  | NA             | NA              | NA                | NA              | NA            |
|   | Number Specimens  | 1              | 1              | 1                   | 1              | 1               | 1                 | 1               | 1             |



Table 14: Autoclaved Transverse and In-Plane Thermal Conductivity

|                              |   |            |          |                     |          |            |                   |            |          |
|------------------------------|---|------------|----------|---------------------|----------|------------|-------------------|------------|----------|
| Material:                    | K6356U / 30% Alum. Filled / 862W Prepreg, Autoclaved  |            |          |                     |          |            |                   |            |          |
|                              |   |            |          |                     |          |            |                   |            |          |
| Resin Content:               | 65.92   | % (w/w)    |          | Composite Density:  |          | 1.7780     | g/cm <sup>3</sup> |            |          |
| Fiber Volume:                | 35.10   | %          |          | Fiber Areal Weight: |          | 154.0      | gsm               |            |          |
| Ply Thickness:               | 0.0081  | inches     |          |                     |          |            |                   |            |          |
|                              |   |            |          |                     |          |            |                   |            |          |
|                              |   |            |          |                     |          |            |                   |            |          |
| Test Method:                 | P2SI's Transverse (TT) and In-Plane (IP) Thermal Conductivity Properties [45, 0, -45, 90] <sub>3s</sub> |            |          |                     |          |            |                   |            |          |
| Normalization:               | Normalize to 50% fiber volume   |            |          |                     |          |            |                   |            |          |
|                              |   |            |          |                     |          |            |                   |            |          |
| Test Temperature (°F)        |   | RT-DRY-TT  |          | RT-WET-TT           |          | RT-DRY-IP  |                   | RT-WET-IP  |          |
| Moisture Saturation (%)      |   | 0.0        |          | 0.364               |          | 0.0        |                   | 0.364      |          |
| Environmental Conditioning   |   | None       |          | Wet                 |          | None       |                   | Wet        |          |
| Thermal Property             |   | Normalized | Measured | Normalized          | Measured | Normalized | Measured          | Normalized | Measured |
| Thermal Conductivity (W/m*K) | Mean (W/m*K)  | 1.603      | 1.125    | 1.815               | 1.274    | 28.623     | 20.093            | 25.218     | 17.703   |
|                              | Minimum   | 1.503      | 1.055    | NA                  | NA       | 26.093     | 18.317            | 21.705     | 15.237   |
|                              | Maximum   | 1.702      | 1.195    | NA                  | NA       | 31.151     | 21.868            | 28.732     | 20.170   |
|                              | Standard Deviation (W/m*K)  | 0.141      | 0.099    | NA                  | NA       | 3.577      | 2.511             | 4.969      | 3.488    |
|                              | Number Specimens  | 2          | 2        | 1                   | 1        | 2          | 2                 | 2          | 2        |

Table 15: Compression Molded Transverse RT-DRY Thermal Conductivity

|  |  |                 |                   |                            |                               |                 |       |
|--|--|-----------------|-------------------|----------------------------|-------------------------------|-----------------|-------|
| <b>Material:</b>                               | K6356U / 30% Alum. Filled / 862W Prepreg, Compression Molded             |                 |                   |                            |                               |                 |       |
| <b>Matrix Content:</b>                         | 62.91 (1-3)  | % (w/w)         |                   | <b>Composite Density:</b>  | 1.782 (1) 1.834 (2) 1.839 (3) | g/cc            |       |
| <b>Fiber Volume:</b>                           | 38.50 (1) 34.40 (2) 36.60 (3)  | %               |                   | <b>Fiber Areal Weight:</b> | 154.00 (1-3)                  | gsm             |       |
| <b>Ply Thickness:</b>                          | 0.0072 (1) 0.0084 (2) 0.0079 (3)   | inches          |                   |                            |                               |                 |       |
| <b>Test Method:</b>                            | P2SI Transverse Thermal Conductivity Properties-RT-DRY [0] <sub>16</sub> |                 |                   |                            |                               |                 |       |
| <b>Normalization:</b>                          | NA   |                 |                   |                            |                               |                 |       |
| <b>Test Temperature (°F)</b>                   | CMP-1 (RT)   |                 | CMP-2 (RT)        |                            | CMP-3 (RT)                    |                 |       |
| <b>Moisture Saturation (%)</b>                 | 0.0  |                 | 0.0               |                            | 0.0                           |                 |       |
| <b>Environmental Conditioning</b>              | Dry  |                 | Dry               |                            | Dry                           |                 |       |
| <b>Thermal Property</b>                        | <b>Normalized</b>  | <b>Measured</b> | <b>Normalized</b> | <b>Measured</b>            | <b>Normalized</b>             | <b>Measured</b> |       |
| <b>Transverse Thermal Conductivity (W/m*K)</b> | <b>Mean (W/m*K)</b>  | 2.839           | 2.186             | 3.602                      | 2.478                         | 3.081           | 2.255 |
|  | <b>Minimum</b>   | 2.816           | 2.168             | NA                         | NA                            | NA              | NA    |
|  | <b>Maximum</b>   | 2.861           | 2.203             | NA                         | NA                            | NA              | NA    |
|  | <b>Standard Deviation (W/m*K)</b>  | 0.032           | 0.025             | NA                         | NA                            | NA              | NA    |
|  | <b>Number Specimens</b>  | 2               | 2                 | 1                          | 1                             | 1               | 1     |

Table 16: Compression Molded RT-WET Transverse Thermal Conductivity

|   |  |            |          |                     |                               |            |          |
|---|--|------------|----------|---------------------|-------------------------------|------------|----------|
| Material:                               | K6356U / 30% Alum. Filled / 862W Prepreg, Compression Molded             |            |          |                     |                               |            |          |
|   |  |            |          |                     |                               |            |          |
| Matrix Content:                         | 62.91 (1-3)  | % (w/w)    |          | Composite Density:  | 1.782 (1) 1.834 (2) 1.839 (3) | g/cc       |          |
| Fiber Volume:                           | 38.50 (1) 34.40 (2) 36.60 (3)  | %          |          | Fiber Areal Weight: | 154.0 (1-3)                   | gsm        |          |
| Ply Thickness:                          | 0.0072 (1) 0.0084 (2) 0.0079 (3)   | inches     |          |                     |                               |            |          |
|   |  |            |          |                     |                               |            |          |
| Test Method:                            | P2SI Transverse Thermal Conductivity Properties-RT-WET [0] <sub>16</sub> |            |          |                     |                               |            |          |
| Normalization:                          | NA   |            |          |                     |                               |            |          |
|   |  |            |          |                     |                               |            |          |
| Test Temperature (°F)                   |  | CMP-1 (RT) |          | CMP-2 (RT)          |                               | CMP-3 (RT) |          |
| Moisture Saturation (%)                 |  | 0.363      |          | 0.363               |                               | 0.363      |          |
| Environmental Conditioning              |  | WET        |          | WET                 |                               | WET        |          |
| Thermal Property                        |  | Normalized | Measured | Normalized          | Measured                      | Normalized | Measured |
| Transverse Thermal Conductivity (W/m*K) | Mean (W/m*K)   | 2.782      | 2.142    | 3.331               | 2.292                         | 2.977      | 2.179    |
|   | Minimum  | 2.778      | 2.139    | 3.167               | 2.179                         | NA         | NA       |
|   | Maximum  | 2.786      | 2.145    | 3.497               | 2.406                         | NA         | NA       |
|   | Standard Deviation (W/m*K)   | 0.006      | 0.005    | 0.233               | 0.160                         |            |          |
|   | Number Specimens   | 2          | 2        | 2                   | 2                             | 1          | 1        |

Table 17: Autoclaved Fracture Toughness by Mix-Mode Bending

|  |  |                 |                   |                            |            |
|--|--|-----------------|-------------------|----------------------------|------------|
| <b>Material:</b>   | K6356U / 30% Alum. Filled / 862W Prepreg, Autoclaved   |                 |                   |                            |            |
| <b>Matrix Content:</b>                                       | 62.90  | % (w/w)         |                   | <b>Composite Density:</b>  | 1.699 g/cc |
| <b>Fiber Volume:</b>   | 33.90  | %               |                   | <b>Fiber Areal Weight:</b> | 147.0 gsm  |
| <b>Ply Thickness:</b>  | 0.0082   | inches          |                   |                            |            |
| <b>Test Method:</b>  | ASTM D-6671 Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites [0 <sub>16</sub> ] |                 |                   |                            |            |
| <b>Normalization:</b>  | NA   |                 |                   |                            |            |
| <b>Test Temperature (°F)</b>                                 | RT   |                 | RT                |                            |            |
| <b>Moisture Saturation (%)</b>                               | 0.0  |                 | 0.440             |                            |            |
| <b>Environmental Conditioning</b>                            | DRY  |                 | WET               |                            |            |
| <b>Mechanical Property</b>                                   | <b>Normalized</b>  | <b>Measured</b> | <b>Normalized</b> | <b>Measured</b>            |            |
| <b>Mode I Fracture Toughness (G<sub>I</sub>)</b>             | <b>Mean (J/m<sup>2</sup>)</b>  | NA              | 202.95            | NA                         | 158.53     |
|  | <b>Minimum</b>   |                 | 101.51            |                            | 98.50      |
|  | <b>Maximum</b>   |                 | 349.23            |                            | 233.18     |
|  | <b>Standard Deviation (J/m<sup>2</sup>)</b>  |                 | 108.02            |                            | 55.87      |
|  | <b>Number Specimens</b>  |                 | 4                 |                            | 5          |
| <b>Mode I Fracture Toughness (G<sub>I</sub>)</b>             | <b>Mean (J/m<sup>2</sup>)</b>  | NA              | 52.49             | NA                         | 35.92      |
|  | <b>Minimum</b>   |                 | 26.82             |                            | 22.12      |
|  | <b>Maximum</b>   |                 | 93.99             |                            | 53.21      |
|  | <b>Standard Deviation (J/m<sup>2</sup>)</b>  |                 | 29.11             |                            | 12.97      |
|  | <b>Number Specimens</b>  |                 | 4                 |                            | 5          |
| <b>Percent Mode II Fracture Toughness (% G<sub>II</sub>)</b> | <b>Mean (%)</b>  | NA              | 20.52             | NA                         | 18.41      |
|  | <b>Minimum</b>   |                 | 18.49             |                            | 22.12      |
|  | <b>Maximum</b>   |                 | 21.53             |                            | 53.21      |
|  | <b>Standard Deviation (%)</b>  |                 | 1.38              |                            | 0.12       |
|  | <b>Number Specimens</b>  |                 | 4                 |                            | 5          |

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| REPORT DOCUMENTATION PAGE  |                             |                              |                                       |   | Form Approved<br>OMB No. 0704-0188                          |  |
|--|-----------------------------|------------------------------|---------------------------------------|---|---|--|
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| 1. REPORT DATE (DD-MM-YY)<br>November 2013   |                             | 2. REPORT TYPE<br>Final      |                                       | 3. DATES COVERED (From - To)<br>7 April 2011- 15 October 2013                   |   |  |
| 4. TITLE AND SUBTITLE<br>INNOVATIVE APPROACH FOR HIGH STRENGTH, HIGH THERMAL CONDUCTIVE COMPOSITE MATERIALS: Data Base   |                             |                              |                                       | 5a. CONTRACT NUMBER<br>FA8650-11-C-5103   |   |  |
|  |                             |                              |                                       | 5b. GRANT NUMBER  |   |  |
|  |                             |                              |                                       | 5c. PROGRAM ELEMENT NUMBER<br>65502F  |   |  |
| 6. AUTHOR(S)<br>Robert J. Jurek and David B. Curliss   |                             |                              |                                       | 5d. PROJECT NUMBER<br>3005  |   |  |
|  |                             |                              |                                       | 5e. TASK NUMBER   |   |  |
|  |                             |                              |                                       | 5f. WORK UNIT NUMBER<br>X0TQ  |   |  |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><br>Performance Polymer Solutions Inc. (P <sup>2</sup> SI)<br>2711 Lance Drive<br>Moraine, OH 45409-1501   |                             |                              |                                       | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER                                     |   |  |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><br>Air Force Research Laboratory<br>Materials and Manufacturing Directorate<br>Wright-Patterson Air Force Base, OH 45433-7750<br>Air Force Materiel Command<br>United States Air Force   |                             |                              |                                       | 10. SPONSORING/MONITORING AGENCY<br>ACRONYM(S)<br>AFRL/RXCC                     |   |  |
|  |                             |                              |                                       | 11. SPONSORING/MONITORING AGENCY<br>REPORT NUMBER(S)<br>AFRL-RX-WP-TM-2013-0229 |   |  |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br>Approved for public release; distribution unlimited.  |                             |                              |                                       |   |   |  |
| 13. SUPPLEMENTARY NOTES<br>PA Case Number: 88ABW-2013-5423; Clearance Date: 20 Dec 2013. Report contains color. For additional information see AFRL-RX-WP-TR-2013-0216.  |                             |                              |                                       |   |   |  |
| 14. ABSTRACT ( <i>Maximum 200 words</i> )<br>Using the format of Mil Handbook 17, a complete data base of the results of experimental efforts to determine hybrid matrix pitch fiber composites. Testing was performed on multiple pitch fiber types, from which we were able to down select K6356U pitch fiber with balanced TC and strength properties. A prepreg processing line was created capable of infusing the unidirectional pitch fiber tape. This processing line has the capability to be used with other fiber types as well. Aluminum-filled composites were manufactured using a resin exfusion process as well as conventional compression molding. It was found that compression molding outperforms autoclaving in both thermal and mechanical properties.  |                             |                              |                                       |   |   |  |
| 15. SUBJECT TERMS<br>data base report, composite materials, pitch carbon fiber, thermal conductivity, highly graphite fibers, composites   |                             |                              |                                       |   |   |  |
| 16. SECURITY CLASSIFICATION OF:  |                             |                              | 17. LIMITATION<br>OF ABSTRACT:<br>SAR | 18. NUMBER<br>OF PAGES<br>22  | 19a. NAME OF RESPONSIBLE PERSON (Monitor)                   |  |
| a. REPORT<br>Unclassified  | b. ABSTRACT<br>Unclassified | c. THIS PAGE<br>Unclassified |                                       |   | Roger Gerzeski  |  |
|  |                             |                              |                                       |   | 19b. TELEPHONE NUMBER (Include Area Code)<br>(937) 904-4323 |  |